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Optimization Calculation on Maneuverability Index of Small Scale Ship Model

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Abstract

The small-scale self-propelled ship model plays an important role in studying the navigability of a waterway. The model is usually calibrated with *Z*-type tests. In order to improve traditional *Z*-type tests, this paper developed new methods for estimating ship model maneuverability indexes. Based on momentum theorem, all parameters such as rudder angle, drift angle, heading angle associate with turning quality index, *K*, and turning lag index, *T*, were simplified to be related to the time parameters associated with ship movement. The methods were verified with observed data based on real ships.

Keywords: Small scale ship model; ship maneuverability; maneuverability index; Z type test;rudder angle

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1. Introduction

Using small scale self-propelled ship model to research the problem of navigation was a widely used

Nomenclature

A	small scale ship model
B	ship maneuverability
C	Z type test

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technology in developed countries[1]. Compared with the normal hydraulic model, physical ship model test could reflect the comprehensive effect authentically on the ship's navigation effected by the channel flow and boundary conditions and it could also reflect the interaction of ship and the flow conditions which was difficult to be described by hydraulic model test. Therefore, small scale ship model technology was deemed to be useful and used widely on the navigation and the design of channel regulation. The ship model maneuverability was the important indexes on ship model design and its parameters directly affected the design of model even the navigation structures[2]. Thus, the purpose of this paper was to optimize the maneuverability index and drew relevant empirical formula combining theory and ship model test[3].

2. Traditional Z type test and other related questions

2.1. Analysis of the test results

Traditional Z type test steps

(1). To be maintaining constant voyage with stated speed[4].

(2). Turn the rudder right for angle10^{o}and maintained.

(3). Turn the rudder right for angle 10^o and maintained when the angle of ship head turn left to maximum angle 10^o.

(4). So again and again. In the process of the test, the time of the rudder angle reached the designated location, the characteristics time of turning head and the angle of inertia exceed should be accurated record. Drew the curve δ —t, ψ—t with these data as Fig2.1

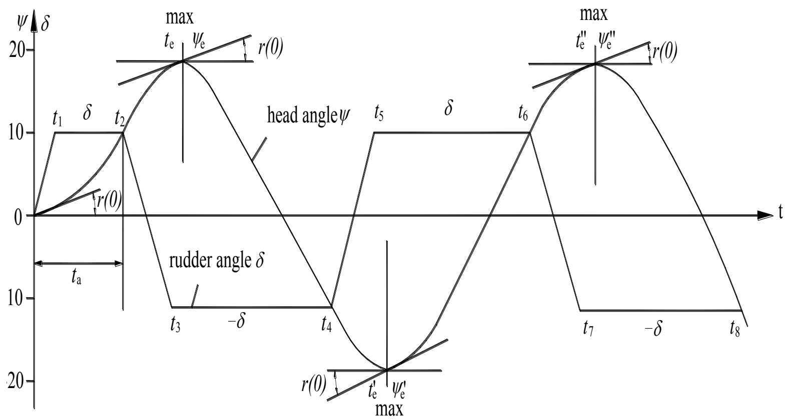

Fig.1. the test curve of θ—t and δ —t

In the chart above, t_a was the initial rotary time of the rudder , that was the time needed for the ship turning certain angle after turning the rudder for the angle δ .The greater t_a the worse of the initial turning function and vice versa. The angle of inertia exceed and the lag time of turning head could be used for evaluating the ability of ship inhibitory deflection[5].The angle of inertia exceed refer to the difference between the instantaneous angle steering opposite rudder and the maximum heading angle . As shown in figure ψ_1, ψ_2, ψ_3. The lag time of turning head T refer to the time intervals between the instantaneous time of the rudder passing the position of zero angle to the maximum turning angle as shown in figure T_L, T_{L2}, T.

2.2. Calculation the K and T index

Analysed the results of Z type test with the method of *K—T*, that was the standard method of *K—T* .If considering the fixed rudder of rudder angle δ_r , the approximation equation of the movement of ship maneuverability should be

$$T\dot{r}+r=K(\delta+\delta_r) \tag{1}$$

Parameters: $\dot{r}$ —angle acceleration velocity of rotation
r —angle velocity of rotation
The integral style

$$\int_0^t T\dot{r}+\int_0^t r=\int_0^t K(\delta+\delta_r) \tag{2}$$

The results

$$\mathrm{T}\left[\mathrm{r}(\mathrm{t})-r(0)\right]+\left[\psi(t)-\psi(0)\right]=K\left[\delta_r(t-0)+\int_0^t \delta dt\right] \tag{3}$$

(1) Integrated 0→ t'_e , 0→ t''_e the results would be

$$\begin{aligned}\psi(t'_e)&=K\int_0^{t'_e}\delta dt+K\delta_r t'_e\\ \psi(t''_e)&=K\int_0^{t''_e}\delta dt+K\delta_r t''_e\end{aligned} \tag{4}$$

(2) Calculated the two equations and the results *K* and δ_r would be record as $K_{6,8}$。
(3) Integrated t from $0\rightarrow t_e$the results would be

$$\psi(t_e)=K\int_0^{t_e}\delta dt+K\delta_r t_e \tag{5}$$

Took the δ_r to above equation and we could get the results *K* recorded as K_4 , then take the average results $K_{6,8}$ and K_4 to this test as the final *K*.

$$K=\frac{1}{2}\left(K_{6,8}+K_4\right) \tag{6}$$

The result *T* of this test would be

$$T=\frac{1}{2}\left[T_4+\frac{1}{2}\left(T_6+T_8\right)\right] \tag{7}$$

2.3. Related problems of theoretical calculation

(1) The model must met the Reynolds number similar at the same time met the gravity similar conditions .The Reynolds number always be smaller than that was for the real ship[6].

(2)As known by the above figure, the initial rotary time of the ship t_a was influenced by inertia, the time of the initial turning must greater than the ship model .So the index of *K, T* calculated through the ship model must be less than the real ship.

(3)The test conditions of Z style test demanded rigorous and the real wind and waves conditions were considered more complicated than the test which was affected the actual value of *K, T* index[7].

3. Optimization calculation of *K* and *T* index

This theory based on momentum theorem[8] and simplified all relevant parameters of *K, T* index to time parameter which was concise, clear and significance. The momentum theorem of real ship would be

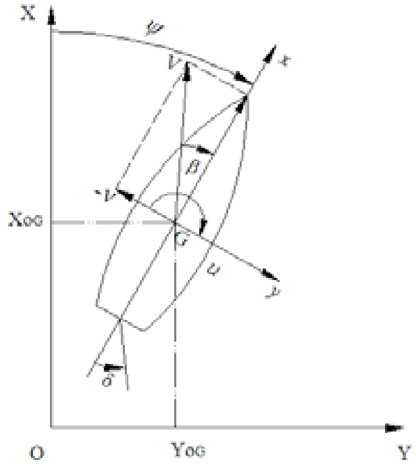

Fig.2. the coordinate system of ship motion

$$\frac{d}{dt}\int_{\tau}\rho V\delta\tau=\int_{\tau}\rho F\delta\tau\ ,\rho\frac{dVi}{dt}=\rho Fi \tag{8}$$

$$\left.\begin{aligned}MV_x\text{-}MV_x\cos\psi=F_xT_{\psi x}\\ MV_y\text{-}MV_y\sin\psi=F_yT_{\psi y}\end{aligned}\right\}\ ,T_{\psi}=\sqrt{T_{\psi x}^2+T_{\psi y}^2} \tag{9}$$

$$\left.\begin{aligned}MV_x\text{-}MV_x\cos\delta=F_xT_{\delta x}\\ MV_y\text{-}MV_y\sin\delta=F_yT_{\delta y}\end{aligned}\right\}\ ,T_{\delta}=\sqrt{T_{\delta x}^2+T_{\delta y}^2} \tag{10}$$

$$K=\frac{T_{\psi}+T_{\delta}}{T_{\psi}}=1+\frac{T_{\delta}}{T_{\psi}} \tag{11}$$

$$\left.\begin{aligned}MV_x\text{-}MV_x\cos\beta=F_xT_{\beta x}\\ MV_y\text{-}MV_y\sin\beta=F_yT_{\beta y}\end{aligned}\right\}\ ,T_{\beta}=\sqrt{T_{\beta x}^2+T_{\beta y}^2} \tag{12}$$

$$T=\frac{T_{\beta}}{T_{\psi}} \tag{13}$$

Here , ψ mean the ship heading angle, δ means the rudder angle, β mean ship drift angle, V mean the velocity vector of ship of gravity, T_{ψ} mean the time for ship head turning the angle ψ , T_{δ} mean the time for rudder turning the angle δ , T_{β} mean the time for drifting the angle β . Simulated *K* and *T* index of real ship and fleet using the above formula was shown in Table1. Compared with the test data of West branch and the model simulation as shown the following diagram[17-19]. The model and test data obtained very well fitting and this method is feasible [9].

Table 1. Simulation of the parameters K' and T' with 15 ° rudder of the real ship and the model of three gorges project

Fleet		Rudder area	Weight(kg)	Velocity(m/s)	Head angle	Rudder angle	Drift angle	K′	T′
Real ship	Nine barges	100 %	3000	3.155	15	15	10	1.482	0.635
	Six barges	100 %	2000	3.567	15	15	10	1.574	0.650
	Threebarges	100 %	1000	4.289	15	15	10	1.626	0.677
1/100Ship model	Nine barges	100 %	30	0.3155	15	15	10	1.390	0.552
		80 %*	30	0.3155	15	15	10	1.358	0.598
	Threebarges	100 %	10	0.4289	15	15	10	1.475	0.620
		80 %*	10	0.4289	15	15	10	1.420	0.699
1/110Ship Model	Nine barges	100 %	27	0. 3008	15	15	10	1.425	0.520
		80 %*	27	0.3008	15	15	10	1.414	0.635
		60 %	27	0.3008	15	15	10	1.398	0.688
	Six barges	100 %	18	0.3401	15	15	10	1.466	0.570
		80 %*	18	0.3401	15	15	10	1.445	0.666
		60 %	18	0.3401	15	15	10	1.430	0.700
	Threebarges	100 %	9	0.4089	15	15	10	1.485	0.625
		80 %*	9	0.4089	15	15	10	1.466	0.715
		60 %	9	0.4089	15	15	10	1.450	0.765

Table 2. Comparison of the parameters K' and T' with 15 ° rudder of the real ship and the model of three gorges project

\		Rudder area	K′		T′		P		Velocity(m/s)
			Val ue	Deviation	Value	Deviation	Value	Deviation	
Realship	Nine barges	100 %	1.540	——	0.640	——	0.761	——	3.155
	Sixbarges	100 %	1.640	——	0.653	——	0.801	——	3.567
	Threebarges	100 %	1.680	——	0.695	——	0.789	——	4.289
1/100Ship model	Nine barges	100 %	1.408	- 8.57	0.564	-11.88	0.749	- 1.57	0.3155
		80 %*	1.371	-10.97	0.646	+ 0.94	0.674	-11.40	0.3155
	Three barges	100 %	1.498	-10.83	0.638	- 8.20	0.742	- 5.96	0.4289
		80 %*	1.451	-13.63	0.716	+ 3.02	0.699	-15.20	0.4289
1/110Ship mode	Nine barges	100 %	1.453	-5.65	0.531	- 16.90	0.797	+4.73	0.3008
		80 %*	1.430	-7.14	0.644	+0.40	0.704	-7.49	0.3008
		60 %	1.404	-8.33	0.694	+8.40	0.660	-13.27	0.3008
	Six barges	100 %	1.478	-9.90	0.580	-11.17	0.774	-3.37	0.3401
		80 %*	1.451	-11.52	0.670	+2.63	0.697	-12.98	0.3401
		60 %	1.439	-12.36	0.726	+11.23	0.658	-17.88	0.3401
	Three barges	100 %	1.494	-11.07	0.635	-8.70	0.742	-5.99	0.4089
		80 %*	1.471	-12.42	0.721	+3.76	0.675	-14.48	0.4089
		60 %	1.451	-13.67	0.789	+14.82	0.628	-20.34	0.4089

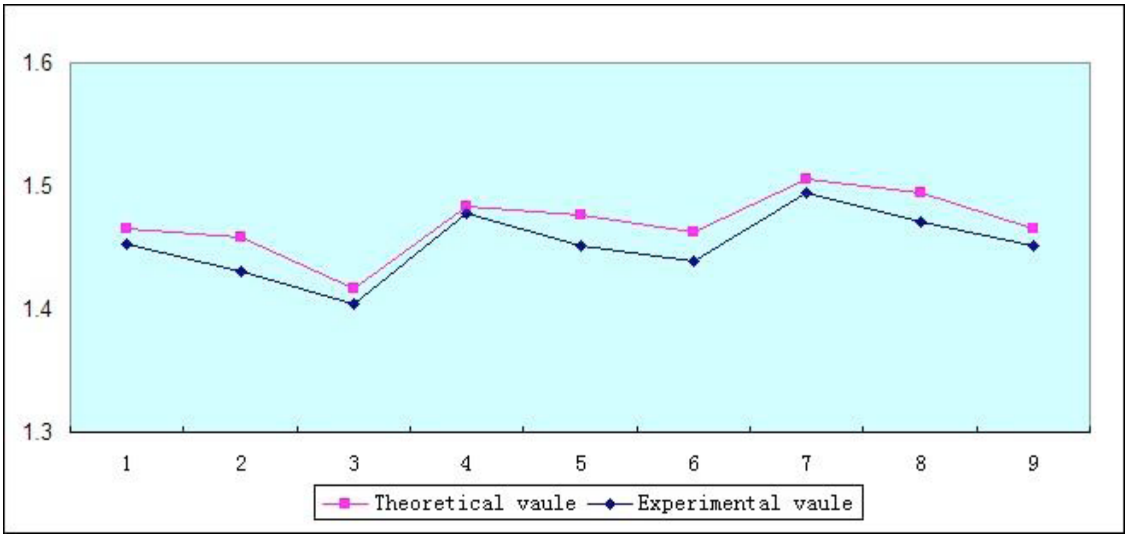

Fig. 3. The simulation curves of $K^{/}$

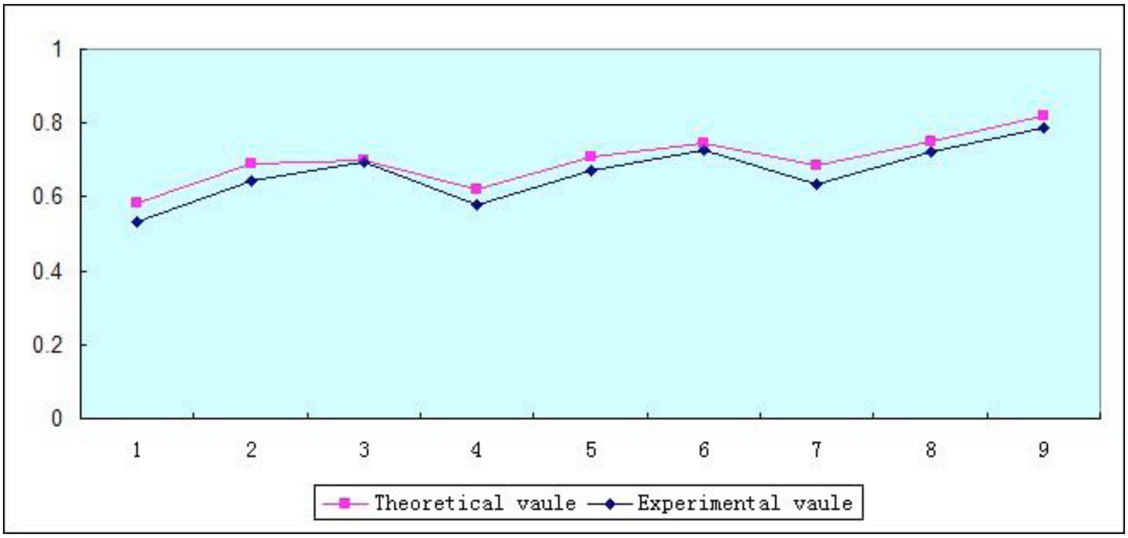

Fig. 4. The simulation curves of $T^{/}$

The error analysis

The error equation would be

$$y = f\left(x_1, x_2, \ldots x_n\right) \tag{14}$$

y —experimental value

x_i —simulation value

Taylor series

$$\Delta y = \frac{\partial f}{\partial x_1}\Delta x_1 + \frac{\partial f}{\partial x_2}\Delta x_2 + \ldots + \frac{\partial f}{\partial x_n}\Delta x_n \tag{15}$$

The relative error

$$\delta = \frac{\Delta y}{y} = \frac{\partial f}{\partial x_1}\frac{\Delta x_1}{y} + \frac{\partial f}{\partial x_2}\frac{\Delta x_2}{y} + \ldots + \frac{\partial f}{\partial x_n}\frac{\Delta x_n}{y} = \frac{\partial f}{\partial x_1}\delta_1 + \frac{\partial f}{\partial x_2}\delta_2 + \ldots + \frac{\partial f}{\partial x_n}\delta_n \tag{16}$$

Take the experimental value and the simulation value to above equation

$$\delta_{k\max} = \frac{\Delta y}{y} = \frac{\partial f}{\partial x_{k1}}\frac{\Delta x_{k1}}{y} + \frac{\partial f}{\partial x_{k2}}\frac{\Delta x_{k2}}{y} + \ldots + \frac{\partial f}{\partial x_{kn}}\frac{\Delta x_{kn}}{y} = \pm 2\% \tag{17}$$

$$\delta_{t\max} = \frac{\Delta y}{y} = \frac{\partial f}{\partial x_{t1}}\frac{\Delta x_{t1}}{y} + \frac{\partial f}{\partial x_{t2}}\frac{\Delta x_{t2}}{y} + \ldots + \frac{\partial f}{\partial x_{tn}}\frac{\Delta x_{tn}}{y} = \pm 4\% \tag{18}$$

As known above the *K, T* index simulated through the model was approximate and the model test was feasible [10].

4. Conclusion

K, T index was an important index to express the quality of ship maneuverability and became common international method as its physical meaning. However, the test value usually had certain deviation to that of the real ship because of the test conditions and the influence of scale. Therefore, the method through theoretical calculation and model modification was necessary. In this paper, the author obtain *K, T* index using mathematical modification methods based on the theoretical calculation and Z type test. The simplified ship model corresponded with the real ship through the comparison of model and real data.

References

[1]ZhaoYueLin .*Ship maneuvering*. [M].Dalian:Dalian maritime publishing company, 2000.

[2] Wu Xiuheng .*Ship maneuvering and wave resistance[*M]. Beijing: people's traffic publishing company 1999.

[3] Garthune R S, etc. *The Performance of Model Ships in Restricted Channels In Relation to the Design of a Ship*

[4] LiYing. *Research and application on the capacity of Inland channel[D]*. Nanjing: Hehai university, 2006

[5] Li Xiaobiao. *Simulation of the test data of the velocity of ship model* [J]. Journal of the Yangtze river academy, 2003, 16 (3) : 7 ~ 9.

[6] Li Yibing,.Wang YuLin. *The application of the model ship test technology in the research of port engineering* [J]. Port, 2004, 3: channel 8 to 13.

[7] *International Towing Tank Conference*. Uncertainty analysis for experimental fluid dynamics

[8] Hong Biguang,YuYang. Statistical analysis on K、T index on ship maneuvering[J]. Journal of dalian maritime, 2000, 26 (4) : 29 ~ 33.

[9] CAI Chuang ,CaiRuZhe. *Experimental study on navigation of ship model of regulating the risks Beaches of Yangtze river* [J]. Journal of Chongqing jiaotong University , 2005, (5) : 135 ~139

[10] ShenH C .*Uncertainty analysis of resistance test*[J].Journal of Ship Mechanics1999,3(6)